HYDROLOGIC RESOURCE MONITORING PARAMETERS

Groundwater Quality

Brief Description: The chemistry (quality) of groundwater reflects inputs from the atmosphere, from soil and water-rock reactions (weathering), as well as from pollutant sources such as mining, land clearance, agriculture, acid precipitation, domestic and industrial wastes. The relatively slow movement of water through the ground means that residence times in groundwaters are generally orders of magnitude longer than in surface waters. As in the case of Surface water quality, it is difficult to simplify to a few parameters. However, in the context of geoindicators, a selection has been made of a few important first-order and second order parameters that can be used in most circumstances to assess significant processes or trends at a time-scale of 50-100 years.
The following first order indicators (in **bold**) of change are proposed, in association with a number of processes and problems, and supported by a number of second order parameters:
1. SALINITY: **Cl**, SEC (specific electrical conductance), SO_4, Br, TDS (total dissolved solids), Mg/Ca, $\delta^{18}O$, $\delta^{2}H$, F
2. ACIDITY & REDOX STATUS: **pH, HCO_3, Eh**, DO, Fe, As
3. RADIOACTIVITY: $\mathbf{^{3}H}$, ^{36}Cl, ^{222}Rn
4. AGRICULTURAL POLLUTION: **NO_3**, SO_4, DOC (dissolved organic carbon), K/Na, P, pesticides and herbicides
5. MINING POLLUTION: **SO_4, pH**, Fe, As, other metals, F, Sr
6. URBAN POLLUTION: **Cl, HCO_3, DOC**, B, hydrocarbons, organic solvents
During development and use of an aquifer, changes may occur in the natural baseline chemistry that may be beneficial or detrimental to health (e.g. increase in F, As): these should be included in monitoring programs. The quality of shallow groundwater may also be affected by landslides, fires and other surface processes that increase or decrease infiltration or that expose or blanket rock and soil surfaces which interact with downward-moving surface water.

Significance: Groundwater is almost globally important for human consumption, and changes in quality can have serious consequences. It is also important for the support of habitat and for maintaining the quality of baseflow to rivers. The chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation, and for industrial and other purposes. It also influences ecosystem health and function, so that it is important to detect change and early warnings of change both in natural systems and resulting from pollution.
1. SALINITY: Fresh groundwater may be limited laterally by its interface with sea water and adjacent rock types, or vertically by underlying formation waters. Saline water intrusion into coastal aquifers can result from overpumping of fresh groundwater, or when streamflow decreases (e.g. due to dams or diversions) lead to reduced recharge of aquifers in deltas and alluvial plains. Strong evaporation in areas with shallow water tables may also lead to salinization. Changes in levels of salinity may occur due to natural climate change or due to excessive pumping and irrigation practices that stimulate precipitation of dissolved solids as salts on agricultural lands. It is important to monitor overall changes in salinity using Cl or SEC and, if possible, to characterize the source of the salinity, using one or more secondary indicators.
2. ACIDITY AND REDOX STATUS: Emissions of SOx and NOx from industrial sources have, in places, led to an order of magnitude decrease in mean rainfall pH. This has accelerated natural weathering rates and reduced the buffering capacity of soils and rocks, causing an increase in acidity of shallow groundwaters especially in areas deficient in carbonate minerals. Acidification is a major problem to human and ecosystem health in large areas of North America, Northern Europe, Southeast Asia and South America. The impact on surface waters is exacerbated where the buffering effect of HCO_3 in groundwater baseflow to rivers and lakes is diminished. Changes in the redox status of groundwater (mainly consequent on the reduction of O_2) can also take place rapidly due to microbial or chemical processes in natural systems or as a result of pollution. An increase in acidity (decrease in pH) or a decrease in Eh (redox

potential) may give rise to undesirable increases in dissolved metals. The onset of reducing conditions may, however, have benefits such as in situ de-nitrification.

3. RADIOACTIVITY: Natural background radioactivity can be closely related to the presence or absence of rocks and sediments containing uranium or other naturally radioactive materials. Concentrations of dissolved Rn gas provide one means of detecting the presence of natural radioactivity in groundwater [see karst activity]. Of more significance from an environmental point of view is the possible migration of radionuclides to groundwater from thermonuclear testing, nuclear power plants and military installations.

4. AGRICULTURAL POLLUTION: Nitrate levels in groundwater have been increasing over recent decades in most countries as a result of drainage of excess fertilizers. Nitrate, and other mobile fertilizer-derived parameters such as K (K/Na), DOC and SO_4 serve as important tracers of human-induced environmental degradation, though natural denitrification can also occur under reducing conditions (see ACIDITY). Herbicides and pesticides (insecticides, fungicides) and other agrochemicals may also be mobile in groundwaters and can serve as an index of diffuse pollution beneath agricultural lands over the past 20-30 years. Because analysis is extremely difficult, it is not feasible to use these as indicators. Their presence can, however, be inferred if high concentrations of other indicators are present.

5. MINING POLLUTION: Sulphate derived from the oxidation of sulphide minerals is the best single indicator of pollution from metal and coal mining, oil and gas production, and to a lesser extent from exploration activities. A decrease in pH is generally associated with this process, as are increases in the dissolved loads of Fe and other metals that may contaminate both groundwater and surface waters as acid mine drainage. The problem becomes acute for water supplies and ecosystems as groundwater levels rise following mine closures. F and Sr derived from weathering of associated vein minerals may also serve as secondary indicators.

6. URBAN and INDUSTRIAL POLLUTION: The impact of human habitation and disposal of wastes characterized by numerous chemicals is invariably evident in the quality of local groundwater. Many chemicals enter the ground, but the deterioration of water quality may be assessed by those constituents that are most mobile. One key issue is to protect deeper, uncontaminated aquifers and to monitor the effects of contaminant plumes moving into surrounding areas. Thus, DOC, Cl and HCO_3 represent primary indicators of pollution from towns, cities, landfills and waste dumps. Biological impacts may be measured using indicator organisms such as E. coli. However, harmful microorganisms generally fade out within several hundred meters of flow in groundwater, and an alternative is to measure the breakdown products of these biological processes, such as DOC and HCO_3, Secondary indicators include B (where detergents are used), solvents and hydrocarbons.

Environment where Applicable: The main environments of importance from a global viewpoint are those where major aquifers provide water supplies, especially in bottomland settings with saturated riverine or deltaic sediments, generally of limited thickness and high transmissivity. These environments include temperate regions where adequate supplies of surface water are unavailable, semi-arid and arid regions where groundwater is overwhelmingly the source of supply, and humid tropics where groundwater increasingly provides a bacteriologically 'safe' source of drinking water. It is essential to protect groundwater quality here. Groundwater also provides an important medium for of monitoring associated environmental change in these regions.

Types of Monitoring Sites: Shallow wells, springs and major water supply boreholes where flow is active. Observation holes where flow may be low or stagnant should be avoided. Locations should be along major hydraulic gradients, and some should be located downstream of potential problem areas (e.g. power stations, urban areas, waste disposal sites, agricultural lands) so as to relate individual pollutants to their sources. Wherever possible groundwater monitoring of geoindicators should be integrated with national water quality networks.

Method of Measurement: The first order indicators can be analyzed with relative ease using standard techniques and laboratory equipment. In many cases they may be measured remotely by sensors placed in wells or at points of discharge. To measure small environmental changes requires high precision and accuracy. Changes in acid status should be assessed using HCO_3 rather than pH, which may vary little (except below a pH of 5.5) due to buffering. The second order parameters require more specialized and costly analysis, as do measurements of radioactivity.

Frequency of Measurement: Changes in groundwater quality are usually detectable on a seasonal or annual scale. Dispersion, reaction and mixing ensure that the addition of small amounts of contaminants are commonly difficult to detect. Changes both at a regional scale and in point source effects are important for monitoring. A maximum frequency of 4 times a year is suggested to detect changes in shallow groundwater sources, but annual measurements are sufficient for deeper sources.

Limitations of Data And Monitoring: Care is needed to ensure that sample locations are representative of the groundwater flow regime, vertically as well as horizontally. It is useful to have two sample points, one shallow and one deep, installed at the same site. Spatial variability will impose a limit of what can be achieved, and the resulting network of sites to measure groundwater quality is likely to represent a compromise. Analytical accuracy between widely spaced measurements, possibly by different people, is likely to be a problem. Springs may be stable over the long term, but they can also fluctuate rapidly, due to dual porosity nature of the aquifer, to changes in atmospheric pressure, in precipitation and evaporation rates, or to seismic or volcanic activity, making causes difficult to determine.

Possible Thresholds: International standards for maximum admissible concentrations of various substances in drinking water have been set by WHO (1993) and many national agencies. A range of guidelines exist for the quality of groundwater used for other purposes, such as livestock watering and irrigation.

Key References:

Appelo, C.A.J. & D.Postma 1993. Geochemistry, groundwater and pollution. Rotterdam: Balkema.

Berger, A.R. & W.J.Iams (eds). Geoindicators: Assessing rapid environmental changes in earth systems. Rotterdam: A.A. Balkema. (See papers by W.M.Edmunds and C.B.Dissanayake)

Hem, J.D. 1985. Study and interpretation of the chemical characteristics of natural water. U.S. Geological Survey Water Supply Paper 2254.

WHO, 1993. Guidelines for drinking water quality. Geneva: World Health Organization.

Related Environmental and Geological Issues: In many areas, especially tropical, endemic human diseases (e.g. fluorosis associated with excess F and goitre associated with I deficiency) are related to natural groundwater quality: these diseases may be mitigated by appropriate changes in water chemistry. Changes in groundwater quality may result from other environmental impacts, including acid precipitation, urbanization, agricultural development, land clearance and mining, as detailed above. Variations in groundwater chemistry may also cause changes in habitats and in the salinization of soils and surface waters. Groundwater tritium has been monitored with regard to fallout from nuclear testing in several countries over the past 30 years.

Overall Assessment: Monitoring changes in groundwater quality provides a key indication of both human impacts on the hydrosphere and on the environment in general.

Source: This summary of monitoring parameters has been adapted from the Geoindicator Checklist developed by the International Union of Geological Sciences through its Commission on Geological Sciences for Environmental Planning. Geoindicators include 27 earth system processes and phenomena that are liable to change in less than a century in magnitude, direction, or rate to an extent that may be significant for environmental sustainability and ecological health. Geoindicators were developed as tools to assist in integrated assessments of natural environments and ecosystems, as well as for state-of-the-environment reporting. Some general references useful for many geoindicators are listed here:

Berger, A.R. & W.J.Iams (eds.) 1996. Geoindicators: assessing rapid environmental change in earth systems. Rotterdam: Balkema. The scientific and policy background to geoindicators, including the first formal publication of the geoindicator checklist.

Goudie, A. 1990. Geomorphological techniques. Second Edition. London: Allen & Unwin. A comprehensive review of techniques that have been employed in studies of drainage basins, rivers, hillslopes, glaciers and other landforms.

Gregory, K.J. & D.E.Walling (eds) 1987. Human activity and environmental processes. New York: John Wiley. Precipitation; hydrological, coastal and ocean processes; lacustrine systems; slopes and weathering; river channels; permafrost; land subsidence; soil profiles, erosion and conservation; impacts on vegetation and animals; desertification.

Nuhfer, E.B., R.J.Proctor & P.H.Moser 1993. The citizens' guide to geologic hazards. American Institute for Professional Geologists (7828 Vance Drive, Ste 103, Arvada CO 80003, USA). A very useful summary of a wide range of natural hazards.